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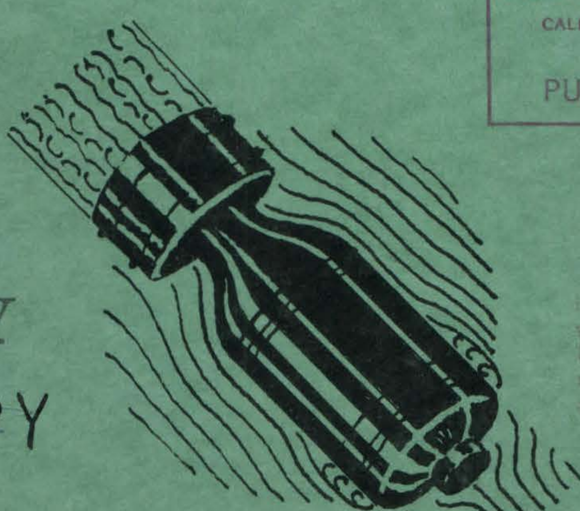
NATIONAL DEFENSE RESEARCH COMMITTEE.

DIVISION SIX-SECTION 6.1

WATER TUNNEL TESTS OF THE

M6, 2.36" A.T. ROCKET.



THE HIGH SPEED WATER TUNNEL

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA.

SECTION № 6.1 - Sr - 207 - 920

COPY № 98

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OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION SIX – SECTION 6.1

MEMORANDUM ON WATER TUNNEL TESTS OF THE M-6, 2.36" A. T. ROCKET SHOWING COMPARISON OF PERFORMANCE WITH THE CONICAL POINTED NOSE COMBINED WITH THREE TYPES OF SHROUD RING TAIL AND WITH SHROUD RINGS OF VARIOUS LENGTHS

BY

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Section No. 6.1-~~sr-207-920~~
HML Rep. No. ND-11.4

July 20, 1943

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ABSTRACT

This report covers Water Tunnel tests of a 2.36" rocket projectile with three types of shroud ring tail. Two of the tails are attached by channel section supporting fins to a stepped nozzle, the fins on one of them being stepped to fit the nozzle contour. The third tail has a streamlined nozzle with smooth supporting fins and shroud ring. The results are given of tests with different shroud lengths on the ring tails with the channel section supporting fins.

CONCLUSIONS

The shroud ring tail with the streamlined nozzle and smooth supporting fins showed the least drag, but also had less stability than the others.

The shroud ring tail, with straight channel section supporting fins and a shroud length of 1-1/2", appears to give the best performance. Increasing the length gives only a slight advantage in stability, which does not appear to justify the additional material. Decreasing the length below 1-1/2" is accompanied by marked decreases in stability.

1. SCOPE AND PURPOSE OF TESTS

This report covers tests on the M-6, 2.36" diameter rocket with the conical pointed nose and three different types of ring tails. It covers the effect of varying the length of the shroud on one of the ring tails and compares the results of these tests with tests on a ring tail, leaving a more completely streamlined nozzle and shroud.

The purpose of the tests was to ascertain the hydrodynamic characteristics of the rocket with a stepped nozzle and shroud ring tail of the dimensions shown on Drawing ND-406-U appended to this report. The design of this tail was in accordance with information received by R. T. Knapp at the Aberdeen Proving Ground and transmitted by telephone to Pasadena on June 4, 1943. Preliminary test results were telephoned to Dr. David Webster at Aberdeen on June 7th and 10th, and confirmed in a letter of June 12th to Dr. Webster. As first made, with a shroud length of 2-3/8", it was designated as Tail No. 31. The tail consists of a thin circular brass shroud supported by three fins of channel section, which are supported on the large diameter of the nozzle. A model was also constructed of a modified design in which the three supporting fins were stepped to fit the nozzle. This model was designated as Tail No. 36 and is shown on Drawing ND-419-U attached.

Tests of both of the above models were made with the full length shrouds and followed by tests of shorter shrouds made by successively cutting off short lengths from the end of the shroud. A shroud length of 1-1/2" appears to show the best results for both models. Results are reported herein for all shroud lengths tested on the first mentioned model (Tails 31-35 incl.) and for only the 1-1/2" shroud length on the tail with the stepped supporting fins (Tail No. 38).

2. DESCRIPTION OF PROJECTILES TESTED

All tests were made on full scale models.

Figure 1 shows the rocket with the Tails Nos. 31 to 35, showing the lengths cut off for successive tests.

Figure 2 shows the 1-1/2" tail (No. 33). This particular tail was made of lucite in order that observation in the Polarized Light Flume could be made of the flow patterns inside the shroud.

Figures 4 and 5 show details of the tail with the straight fin supported only in the large diameter of the nozzle.

FIGURE 1
ROCKET WITH CONICAL POINTED NOSE
AND SHROUD RING TAILS AT THE VARIOUS LENGTHS TESTED
NOSE NO. 8. RING TAILS NOS. 31-35.

FIGURE 2
ROCKET WITH SHROUD RING TAIL NO. 33
TAIL MADE OF LUCITE.

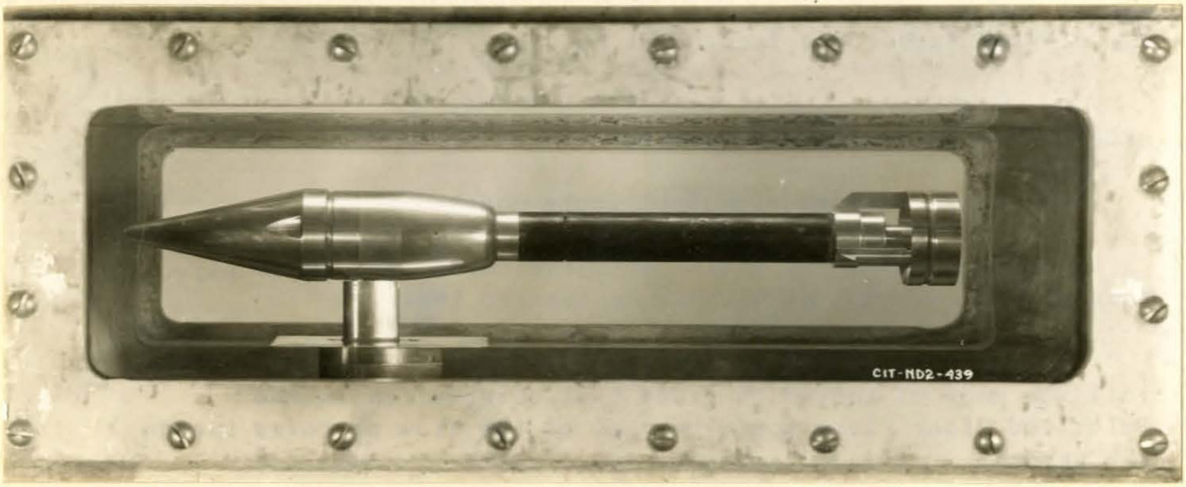

FIGURE 3
ROCKET MOUNTED IN WATER TUNNEL
NOSE NO. 8. RING TAIL NO. 35.

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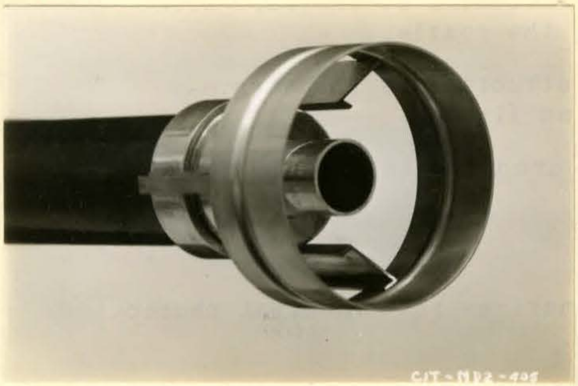


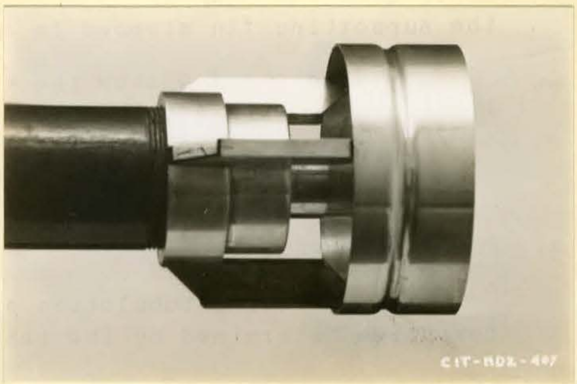


FIGURE 4 FIGURE 5

DETAILS OF RING TAIL NO. 35.

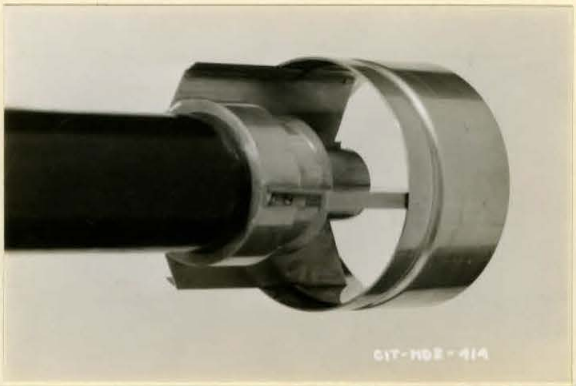
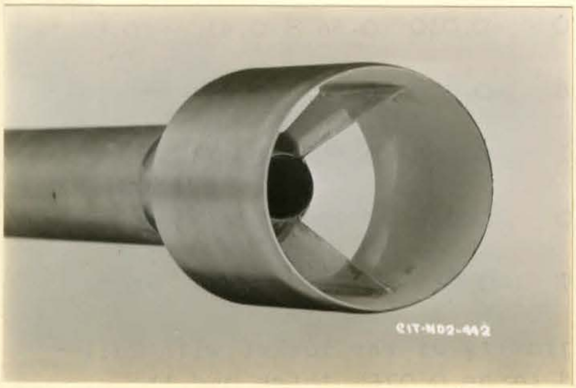


FIGURE 6 FIGURE 7

DETAILS OF RING TAIL NO. 38.



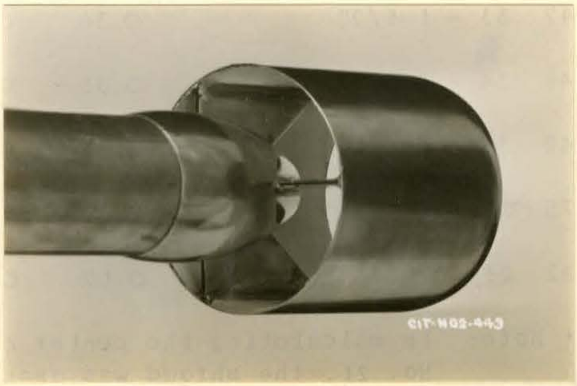


FIGURE 8 FIGURE 9

DETAILS OF RING TAIL NO. 21.

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Figures 6 and 7 show the construction of the tail with the supporting fin stepped to fit the nozzle.

Figures 8 and 9 show the construction of the stream-lined nozzle with smooth shroud and fins.

Detail drawings of all models are attached to this report.

3. FORCE MEASUREMENTS

The following tabulation summarizes the principal characteristics determined by the tests.

Note: All values calculated from averaged, faired data. Length taken as 21.38" for all projectiles tested.

Run No.	Tail No.		Drag coefficient at zero yaw C_D	Cross force coefficient at 4 degrees yaw C_C	Moment coefficient at 4 degrees yaw (about center of gravity) C_M	Distance from nose to center of pressure relative to length, at 4 degrees yaw x/L	Distance from nose to center of gravity relative to length	Distance from C.P. to C.G. relative to length, at 4 degrees yaw
39	31 - 2-3/8"	shroud	0.37	0.20	-0.029	0.55	0.44	+0.11
46	32 - 1-15/16"	"	0.36	0.20	-0.031	0.56	0.43	+0.13
47	33 - 1-1/2"	"	0.36	0.20	-0.030	0.56	0.43	+0.13
48	34 - 1-9/32"	"	0.35	0.18	-0.028	0.55	0.43	+0.12
49	35 - 1-1/16"	"	0.35	0.17	-0.015	0.50	0.42	+0.08
75	38 - 1-1/2"	"	0.37	0.20	-0.022	0.53	0.43	+0.10
82	21 - 2-3/8"	"	0.17	0.19	-0.013	0.51	0.45*	+0.06

* Note: In calculating the center of gravity of the rocket with Tail No. 21, the shroud was assumed to be 0.025" thick and the supporting ribs 1/32" thick, instead of the actual dimensions of the model tail, which is unnecessarily heavy.

From the above tests the following comparisons are to be noted:

1. The drag for all of the tails with stepped nozzle and channel section shroud supports is not markedly different and is about twice as great as the drag with the streamlined ring tail.

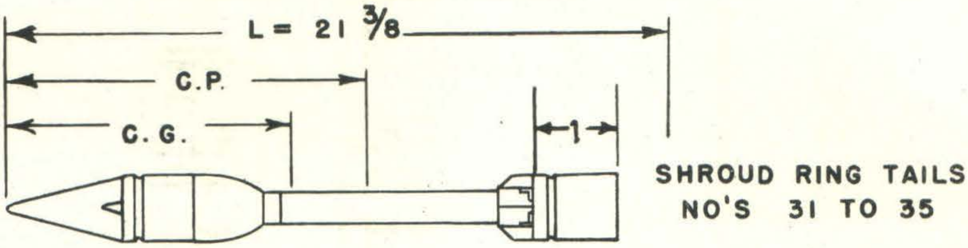
2. The stability, as indicated by the moment coefficient and the location of the center of pressure, is considerably greater for the tails with stepped nozzle and channel section shroud supports than for the streamlined ring tail.

3. As the shroud length is shortened, on the ring tail with the straight channel section supports (Tails 31 to 35) the drag and moment coefficient vary only about 6% and 10% respectively for lengths of 2-3/8", 1-15/16", and 1-1/2". For lengths shorter than 1-1/2", the stability decreases very rapidly. The same variation was evident for varying shroud lengths with the stepped shroud supports. However, at the optimum shroud length for the tail with stepped shroud supports, the drag is slightly greater and the stability less than for the optimum shroud length of the tail with the straight shroud supports.

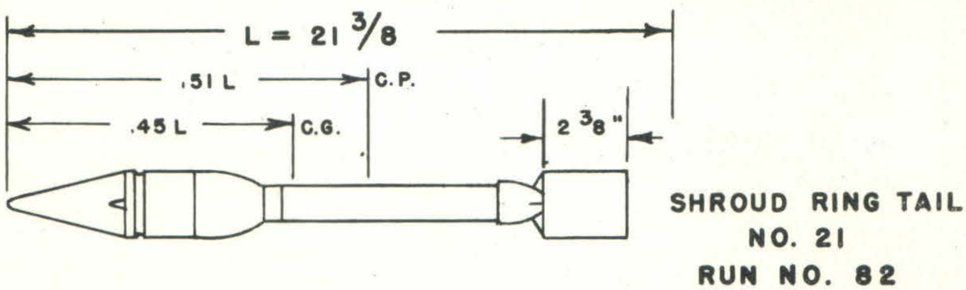
Figure 10 shows diagrammatic sketches of the models tested, with the locations of center of pressure and center of gravity, and the lengths of shroud on the ring tails.

Figure 11 shows the variation of drag and moment for the various lengths of shroud tested on the ring tail with the straight channel section shroud supports.

Figure 12 is a plot of the coefficients as calculated directly from the force measurements. It illustrates the consistency of the test observations and shows the difference in characteristics between the streamlined ring tail (Tail No. 21) and the tail with the straight channel section shroud supports and optimum shroud length (Tail No. 33).



RUN NO.	TAIL NO.	SHROUD LENGTH 1"	SHROUD LENGTH % 1	DISTANCE - NOSE TO CENTER-OF-GRAVITY C.G. % L	DISTANCE - NOSE TO CENTER-OF-PRESSURE C.P. % L
39	31	2 3/8	100	.44	.55
46	32	1 15/16	81.5	.43	.56
47	33	1 1/2	63.0	.43	.56
48	34	1 9/32	53.9	.43	.55
49	35	1 1/16	44.6	.42	.50



HYDRAULIC MACHINERY LABORATORY	CALIFORNIA INSTITUTE OF TECHNOLOGY	
DR	2.36" ROCKET PROJECTILES	SCALE
CH	SHOWING C.G. & C.P. LOCATIONS	
AP	AND SHROUD RING LENGTHS	ND-1007-L

FIG. 10

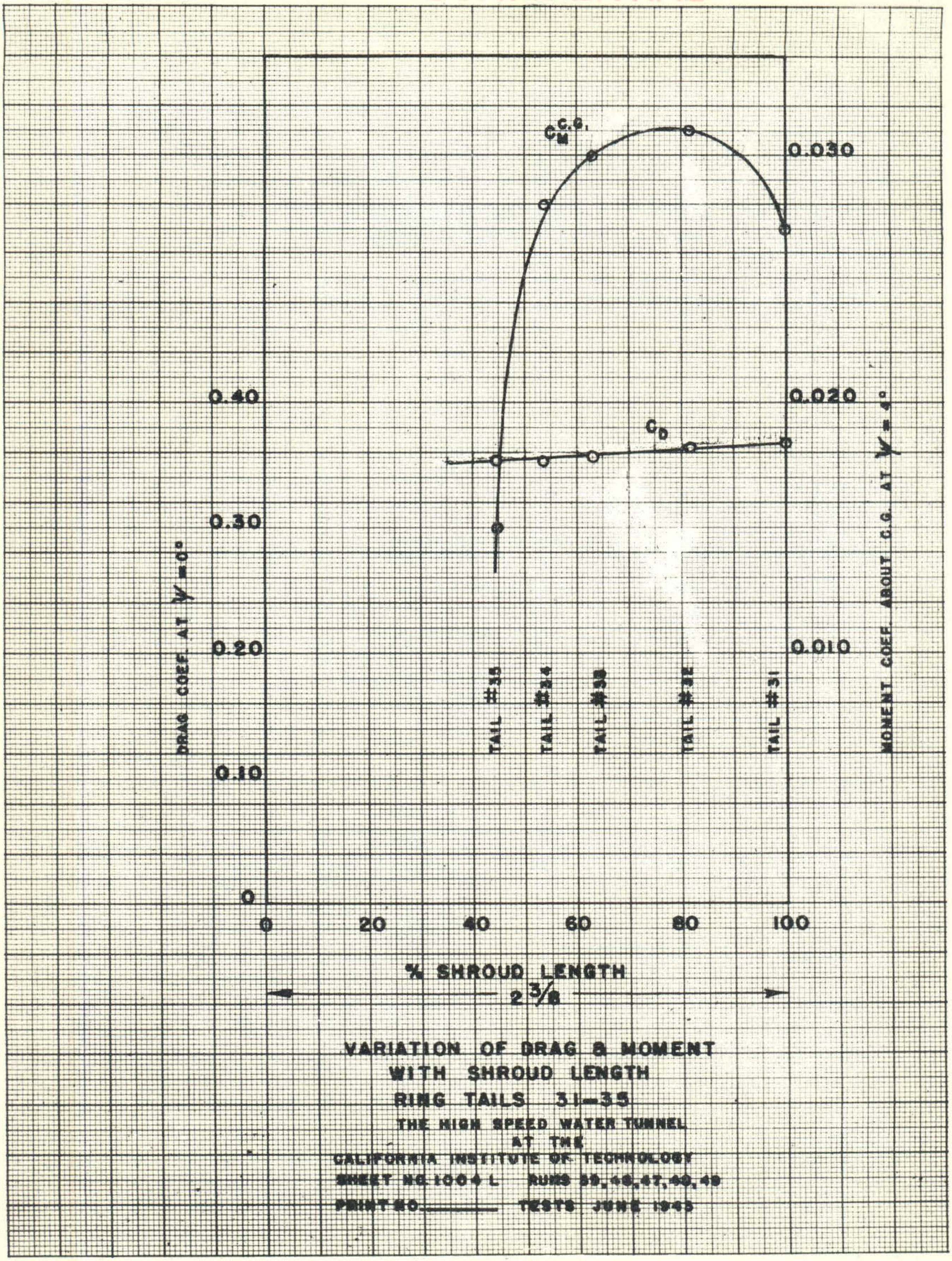
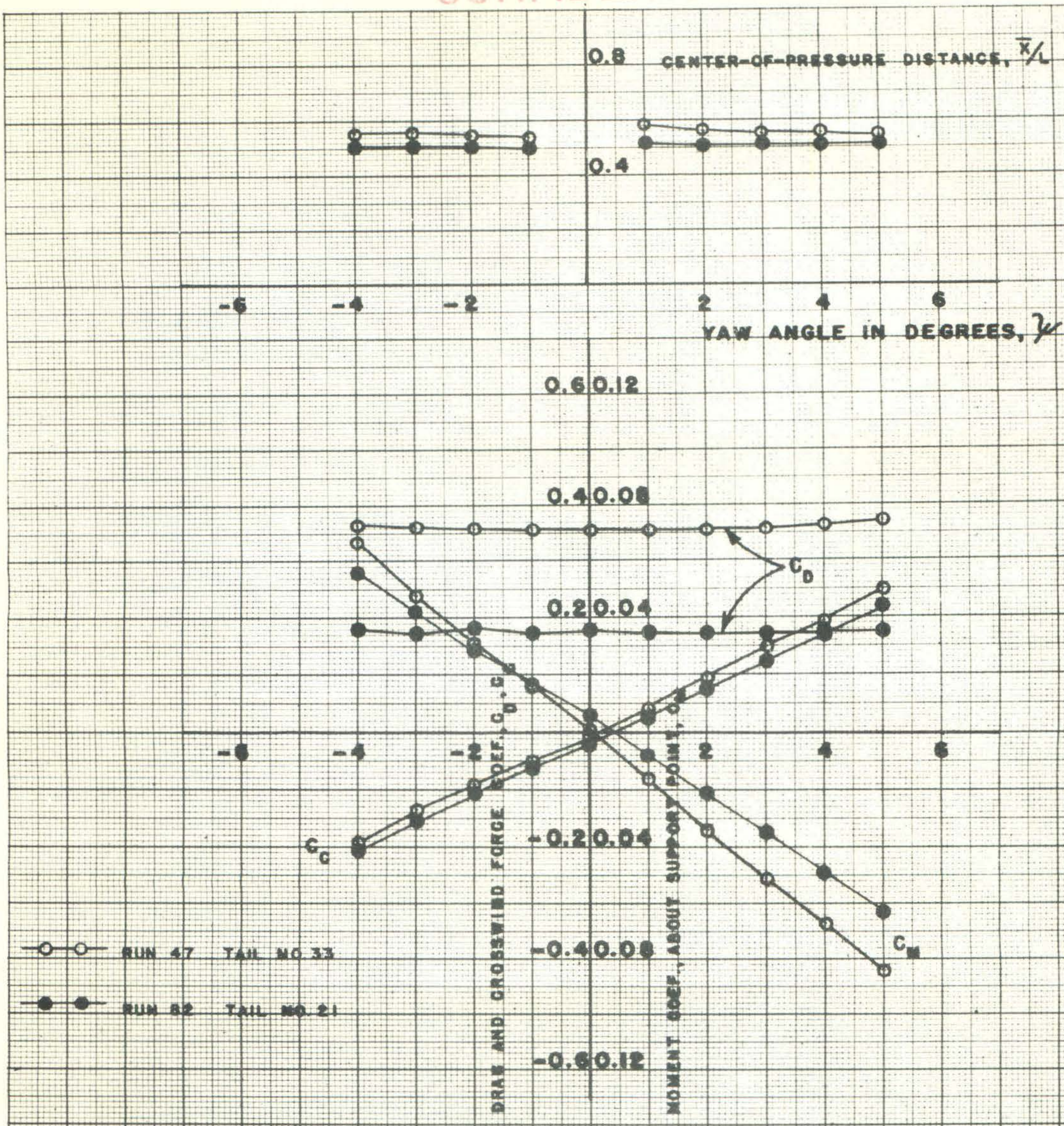

$C_M^{C.G.}$
C_D
0.40
0.30
0.20
0.10
0
0.030
0.020
0.010
DRAG COEF. AT $\psi = 0°$
MOMENT COEF. ABOUT C.G. AT $\psi = 4°$
TAIL #35
TAIL #34
TAIL #33
TAIL #32
TAIL #31
0
20
40
60
80
100
% SHROUD LENGTH
2 3/8
VARIATION OF DRAG & MOMENT
WITH SHROUD LENGTH
RING TAILS 31-35
THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
SHEET NO. 1004 L RUNS
PRINT NO. TESTS JUNE

FIG. 11



CURVES SHOWING COEFFICIENTS AS CALCULATED
DIRECTLY FROM TEST OBSERVATIONS

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY

SHEET NO. 1003 L RUNS 47, 82
PRINT NO. ________ TESTS JUNE 1943

FIG. 12

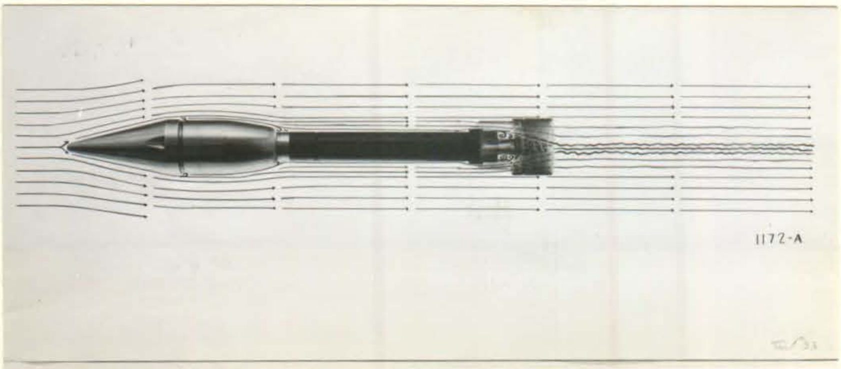


FIGURE 13

FLOW PATTERN AT ZERO YAW
NOSE NO. 8. RING TAIL NO. 33
DRAWING BASED ON OBSERVATIONS OF ACTUAL FLOW.

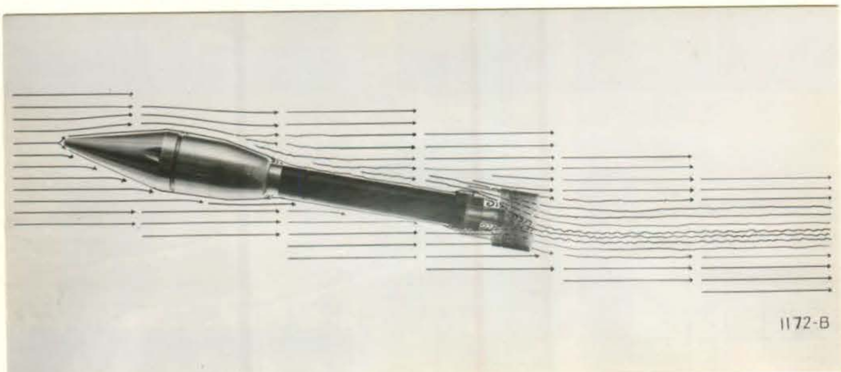


FIGURE 14

FLOW PATTERN AT ABOUT 10 DEGREES YAW
NOSE NO. 8. RING TAIL NO. 33
DRAWING BASED ON OBSERVATIONS OF ACTUAL FLOW.

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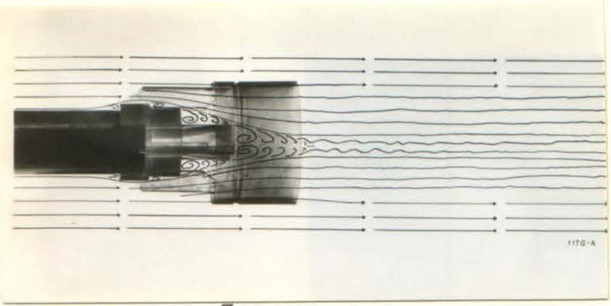

FIGURE 15

FLOW PATTERN PAST RING TAIL
NO. 33 AT ZERO YAW

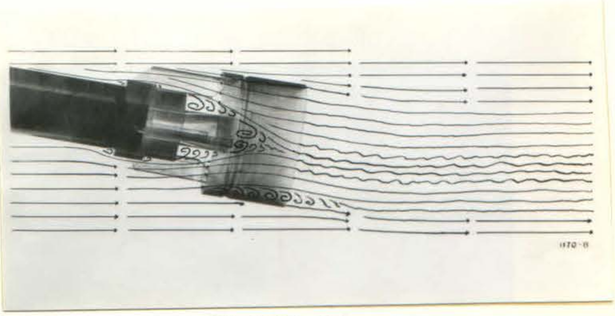

FIGURE 16

FLOW PATTERN PAST RING TAIL
NO. 33 AT ABOUT 10 DEGREES YAW

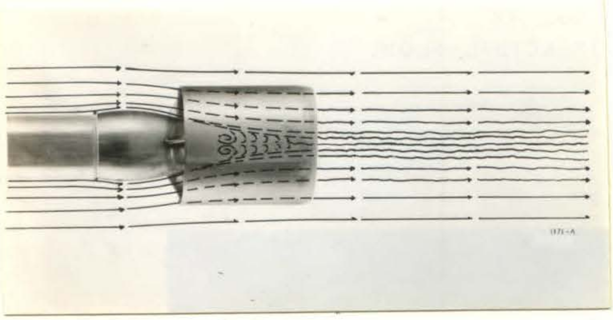

FIGURE 17

FLOW PATTERN PAST RING TAIL
NO. 21 AT ZERO YAW

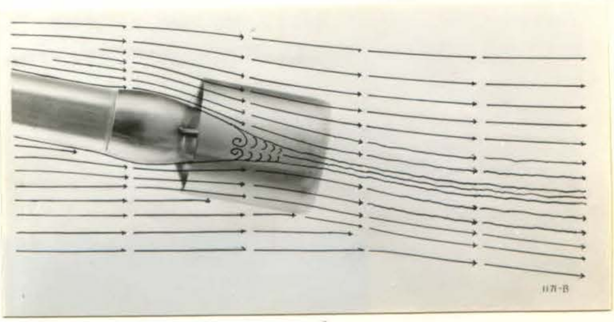

FIGURE 18

FLOW PATTERN PAST RING TAIL
NO. 21 AT ABOUT 10 DEGREES YAW

NOTE:

FIGURES 15 TO 19 ARE BASED ON OBSERVATIONS OF ACTUAL FLOW PAST RING TAIL ASSEMBLIES MADE OF LUCITE

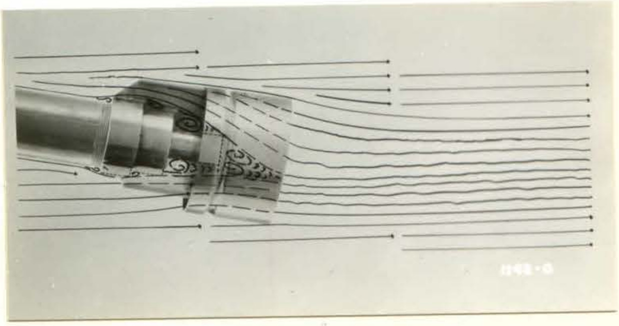

FIGURE 19

FLOW PATTERN PAST RING TAIL
NO. 38 AT ABOUT 19 DEGREES YAW

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4. STUDIES IN POLARIZED LIGHT FLUME

Figures 13 to 19 inclusive are drawings of flow patterns made from observations of the fluid motion about the projectiles in the Polarized Light Flume. The fluid in the flume has asym-metrical physical and optical properties which permit observations of the flow lines when viewed through polarizing plates. The pictures are for flow velocities below the range of the Water Tunnel experiments and the patterns can be considered only quali-tative.

For the flume observations, the ring tail assemblies of nozzle, shroud supports, and shroud, were made of lucite in order to render visible the flow patterns inside the shroud.

Figures 13 and 14 show at zero yaw and about ten degrees yaw the flow patterns around the complete rocket with Ring Tail No. 33.

Figures 15 to 19 show the flow patterns through the various tails at zero yaw and about ten degrees yaw.

The difference in the size of the wake created by the stepped nozzle and the streamlined nozzle is very noticeable and serves to explain the lower drag observed in Ring Tail No. 21.

Comparison of Figures 16 and 18 brings out some differences worth noting. Inside the shroud on the windward side in Figure 16 (Tail No. 33) there is a marked eddy which does not appear in Figure 18 (Tail No. 21). With Tail No. 33 the disturbance near the center and aft of the shroud is heavier than with Tail No. 21 and is more abruptly displaced from the continuation of the pro-jectile center line, although the displacement of the streamlines near and outside the periphery of the shroud appears greater for Tail No. 21 than for Tail No. 33. Figure 19 shows the flow pattern through the stepped fin tail (Tail No. 38) for the same velocity and yaw as Figures 16 and 18. The eddy inside the shroud does not appear, although the drag was slightly higher with this tail than with the others.

5. TUNNEL INSTALLATION AND DESCRIPTION OF FORCES MEASURED

The tests were conducted in the 14" diameter working section of the High Speed Water Tunnel at the California Institute of Technology.[1] Figure 3 shows a projectile installed in the tunnel. In order to reduce the drag tare to a minimum, the rigid supporting spindle is protected from the flow by the streamline shielding shown in the figure. This shielding, which projects to within a few thousandths of an inch of the projectile, is held to a small size in order to reduce interference effects.

(1) Figures refer to references listed at the end of this report.

The forces exerted by the flow on the model can be resolved, in general, into a drag force parallel to the flow, a crosswind force normal to the flow and a moment or torque acting about the point of support. These are the forces measured during the tests. The moment exists only if the model is not supported at the point of application of the resultant of all the hydrodynamic forces. It is clear that the magnitude and sense of the measured moment will change if the point of support is shifted along the body.

The data presented in this report have not been corrected for scale effect, tare, or interference of the model support. However, the results are believed to be close to the correct values. Similar tunnel tests of streamlined projectiles have given data that agree closely with those obtained from full scale field tests. The Water Tunnel test results are applicable in air as well as in water for velocities below that of sound. For air velocities in the neighborhood or above that of sound, the results will not apply.

6. REPRESENTATION OF TEST DATA

The hydrodynamic characteristics are presented in the form of curves of force coefficients as functions of the angle of yaw. In addition, the distance of the center of pressure from the nose of the projectile expressed as a fraction of the length of the projectile is plotted against yaw angle. The center of pressure is defined as the point at which the resultant hydrodynamic force vector intersects the axis of symmetry of the model.

The force coefficients, C_D, for drag and, C_C, for cross wind force are expressed as:

$$C_D = \frac{D}{\rho \frac{V^2}{2} A_D}$$

and

$$C_C = \frac{C}{\rho \frac{V^2}{2} A_D}$$

where

D = measured drag force in lbs

C = measured cross wind force in lbs

ρ = density of water in slugs per cu ft

A_D= area in sq ft of a cross section at the cylindrical portion of the projectile taken normal to the geometric axis of the projectile (= 2.98 sq in, i.e., dia = 2.25" for this projectile)

V = mean relative velocity between the water and the projectile in ft per sec

The moment coefficient is expressed as:

$$C_M = \frac{M}{\rho \frac{V^2}{2} A_D L}$$

where

M = moment in in-lbs measured about any particular point on the geometric axis of the projectile

L = overall length of the projectile in in. (For all combinations of the model projectile discussed in this report L is taken as 21.38")

The distance from the nose of the center of pressure (center-of-pressure distance) as a fraction of the overall projectile length is expressed as:

$$\frac{\bar{x}}{L} = \frac{L' + L''}{L} = \frac{L'}{L} + \frac{M}{L(\ C \cos\psi + D \sin\psi\ )}$$

where

L' = distance in in from the projectile nose to the center of moments

L'' = distance in in from the center of pressure to the center of moments

ψ = yaw angle in degrees

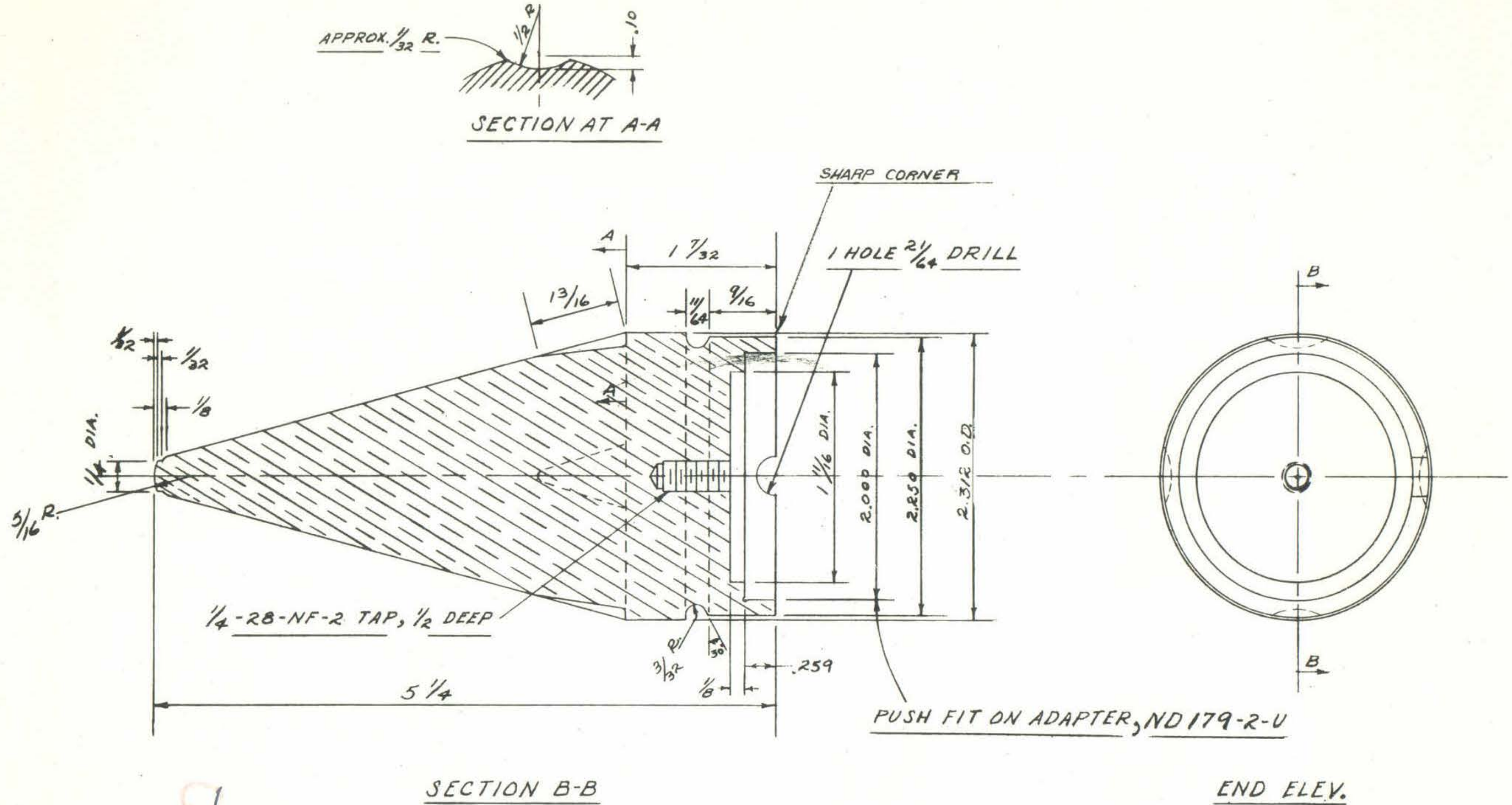
When M is the measured moment the center of moments is at the support point of the model and L" then is the distance from the support point to the center of pressure. The signs of the moment, M, the cross wind force, C, and the yaw angle, ψ, are such that a positive or clockwise moment will tend to increase a positive clockwise yaw angle, while the corresponding positive cross wind force will act in the same direction as the displacement of the projectile nose for a positive yaw.

The curves of force and moment coefficients and of center-of-pressure distance plotted as functions of the yaw angle are useful for a duscussion of the stability of projectiles. Since these tunnel tests are made under steady flow conditions, the results will only indicate the tendency of the projectile to return to or move away from the equilibrium position after a disturbance. Adopting aerodynamic usage, a projectile is said to be "statically" stable if it tends to return to equilibrium when disturbed. In this discussion of static stability, the actual motion following the perturbation is not considered at all. In fact, a projectile may oscillate about the equilibrium position without ever remaining in it. In this case the projectile would be statically stable even though "dynamically" unstable. For a complete discussion of the mode of motion to be expected following a perturbation, i.e. the "dynamic" stability, additional information is necessary.

The condition for equilibrium is satisfied if C_M calculated about the C.G. is equal to zero. In general, for projectiles with axial symmetry, the moment is zero at $\psi = 0^\circ$ so that for equilibrium the projectile is oriented with its axis parallel to the direction of motion. If the projectile is rotated from the equilibrium position so as to give it a positive yaw angle, it is necessary that it have a negative moment coefficient, according to the sign convention adopted, in order that it be statically stable. Thus a negative slope of the curve C_M vs. ψ corresponds to static stability, and a positive slope corresponds to instability. The degree of stability or instability is measured by the magnitude of the slope. The same conclusions are obtained by interpreting the center-of-pressure curves. For symmetrical projectiles, if the center of pressure falls behind the center of gravity, a negative or restoring moment exists and the projectile is statically stable. If the C.P. lies ahead of the C.G., the moment is non-restoring and the projectile is statically unstable. The degree of stability or instability is measured by the distance between the center of gravity and center of pressure.

References:

(1) For complete description see the following report on file in the office of Section 6.1, NDRC, "The High Speed Water Tunnel at the California Institute of Technology", by R. T. Knapp, V. A. Vanoni, and J. W. Daily, June 29, 1942.



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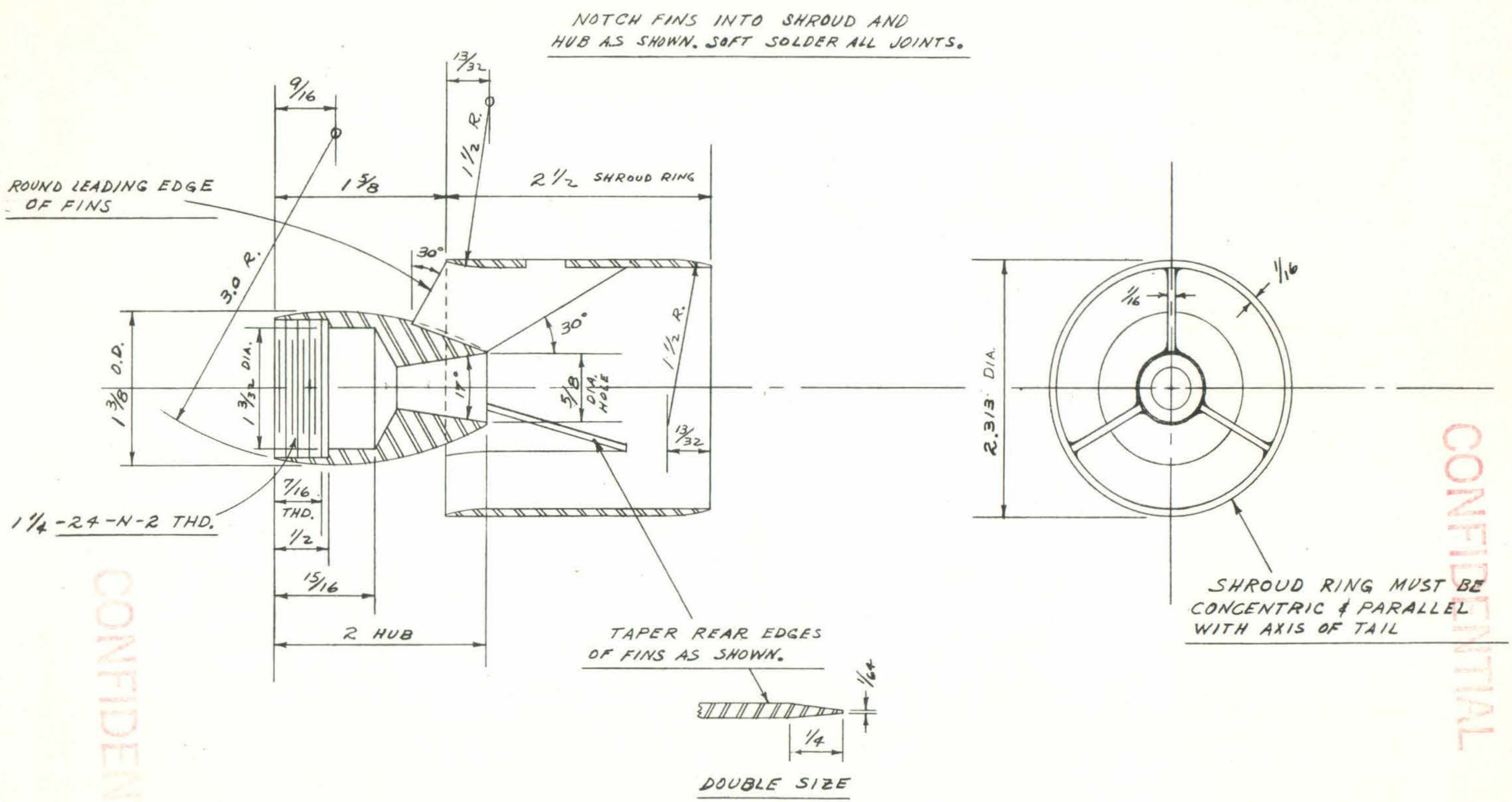
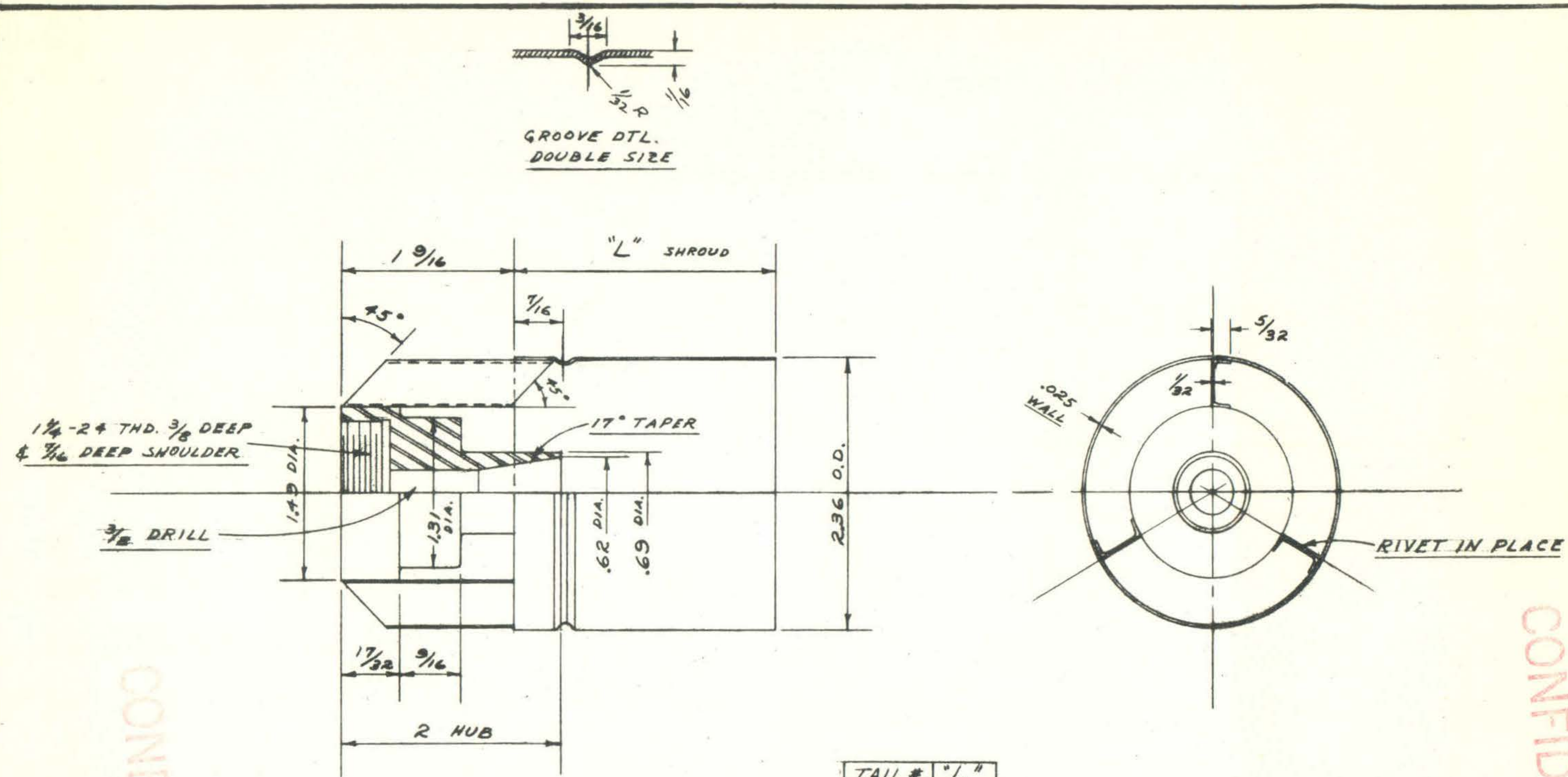
HYDRAULIC MACHINERY LABORATORY C.I.T. PASADENA	
MODEL NOSE #8 ~~FOR~~ 2.36 DIA ROCKET PROJECTILE	
DR. C.R.A. 11-16-42	SCALE ~ FULL
CK HB AP [illegible]	ND-181-8-U



HYDRAULIC MACHINERY LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

MODEL TAIL NO. 21

DR CRA 2-3-43	SCALE ~ 1/1 & 2/1
CH HB	ND-184-21-U
AP JWD	



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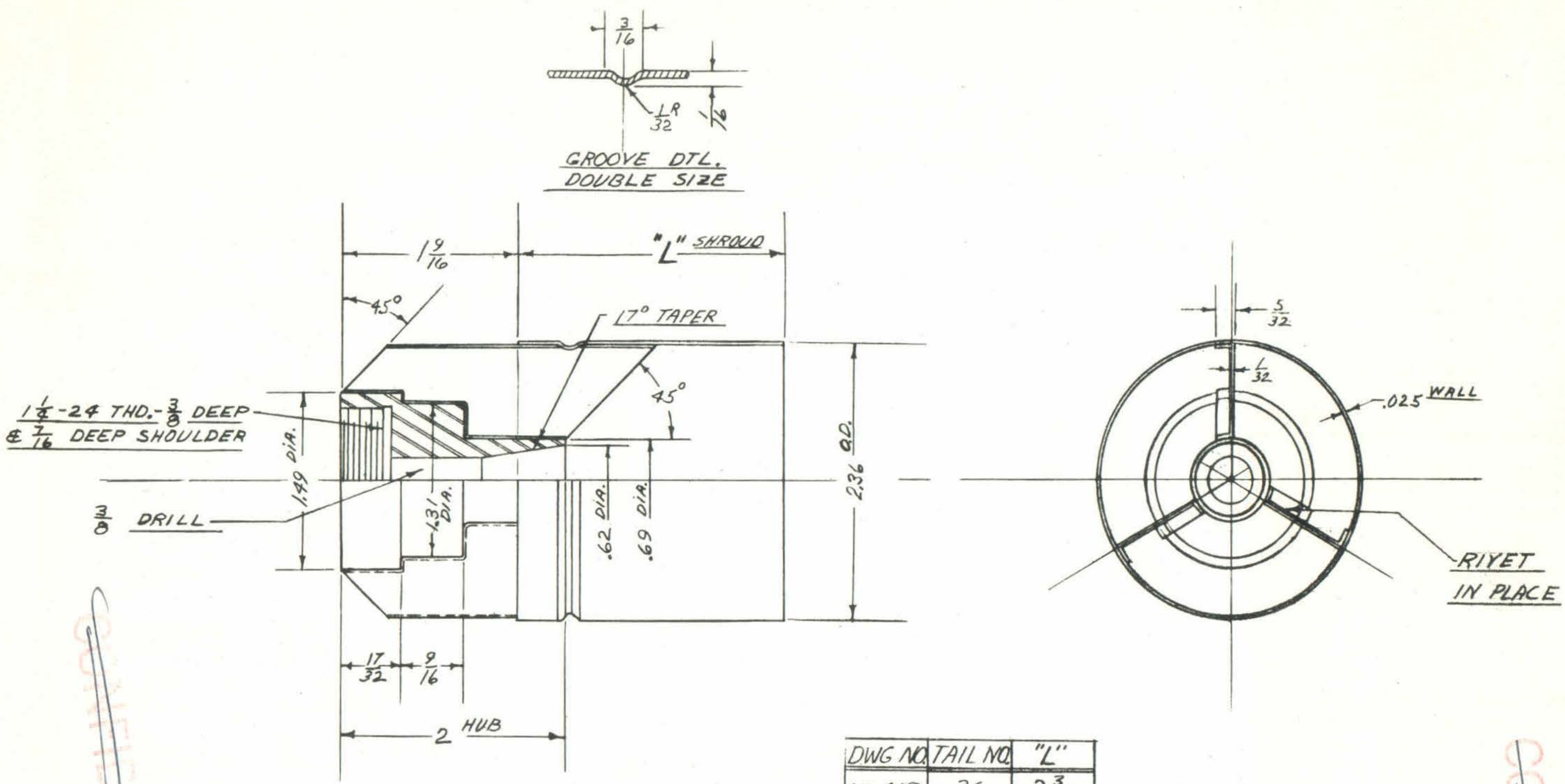
TAIL #	"L"
31	2 3/8
32	1 15/16
33	1 1/2
34	1 9/32
35	1 1/16

LEAVE SQUARE EDGES

FILLETS TO HAVE .03 R.

MAT'L. ~ BRASS

HYDRAULIC MACHINERY LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY PASADENA, CALIFORNIA	
MODEL TAIL #31 thru 35	
DR CRA 6-4-43	SCALE ~ FULL
CH	ND-406 -U
AP JWD	



DWG NO.	TAIL NO.	"L"
ND-417	36	2 3/8
ND-418	37	1 15/16
ND-419	38	1 1/2
ND-420	39	1 9/32
ND-421	40	1 1/16

LEAVE SQUARE EDGES

FILLETS TO HAVE .03 R

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HYDRAULIC MACHINERY LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

MODEL TAIL
#36 THRU 40

DR JWC 6-8-43	SCALE FULL & NOTED
CH CRA 6-8-43	ND-417-421-U
AP JWD –	